A Review of Greenhouse Gas Emission Factors for Fertiliser Production.

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1. Introduction

Given their significant contribution to rising atmospheric greenhouse gas concentrations, accounting for emissions of CO_2, N_2O and CH_4 from agricultural practices has become increasingly important. Emissions of these gases may occur either *directly* during agricultural activities (eg. cultivation and harvesting), or *indirectly* during the production and transport of required inputs (eg. herbicides, pesticides and fertilisers). Life Cycle Assessment (LCA) is commonly employed to undertake a complete evaluation of emissions. In LCA the environmental impacts of products and processes are analysed from 'cradle to grave', such that both direct and indirect emissions from agricultural practices are included.

The production of fertilisers demands much energy and generates considerable greenhouse gas (GHG) emissions. Kongshaug (1998) estimates that fertiliser production consumes approximately 1.2% of the world's energy and is responsible for approximately 1.2% of the total GHG emissions. As such, fertiliser production comprises an important component of agricultural Life Cycle Assessments where system boundaries are wide enough to include indirect emissions from agricultural inputs. Directly calculating GHG emissions from fertiliser production for individual LCA studies is problematic given the large variety of fertilisers used and the complex processes involved in their production. Furthermore, the emissions data required for such calculations are either difficult to obtain or constrained in their extent and quality (Patyk 1996).

Emission factors provide a useful shortcut for use in LCA, avoiding the need for detailed calculations of emissions. An emission factor is a typical quantity of GHGs released to the atmosphere per unit of activity, in this case, per unit weight of fertiliser produced (i.e. g CO_{2-e} / kg fertiliser). Since fertiliser emission factors vary widely depending on production technology, it is preferable to use customised emission factors relevant to the particular plant from which the fertiliser under consideration was produced. Unfortunately, such information is rarely available. The objective of this report is to collate published emission factors for GHGs associated with the production of a range of nitrogen, phosphate and multi-nutrient fertilisers, for use as

1.2. Units

The significant GHG emissions arising from the production of fertilisers are carbon dioxide (CO_2), nitrous oxide (N_2O) and methane (CH_4). In line with international greenhouse accounting practice (IPCC 1996a), emission factors are expressed as carbon dioxide equivalents per unit mass of fertiliser product (eg. *g* $CO_{2\text{-}e}$ */ kg fertiliser*) or element (eg. *g* $CO_{2\text{-}e}$ */ kg N*). This involved some simple calculations:

i. CO_2, N_2O and CH_4 emissions were converted to CO_2 equivalents ($CO_{2\text{-}e}$) using the 'global warming potential' (GWP), which determines the relative contribution of a gas to the greenhouse effect. The GWP (with a time span of 100 years) of CO_2, CH_4 and N_2O is 1, 21 and 310, respectively (IPCC 1996a). $CO_{2\text{-}e}$ emissions for each gas (CO_2, N_2O and CH_4) were summed together to give Total $CO_{2\text{-}e}$. A CO_2:N_2O:CH_4 ratio is included to convey the relative contribution of each gas to Total $CO_{2\text{-}e}$.
ii. Conversion of *mass/product* to *mass/element* (or vice-versa*)* was based on the stated composition of the fertiliser product (i.e. NPK fertiliser: 24% N, 7% P and 3% K). If the composition of the product was unavailable, the ratio was assumed to correspond with equivalent products from other studies.

2. Summary of Literature.

There are few published studies that present emission factors for GHGs arising from fertiliser production (Table 1). All but one of these studies was conducted in Western Europe and analyses were generally coupled with energy LCA. It is likely that more emissions data exist within unpublished reports held within the fertiliser industry or as components of the multitude of agricultural LCA databases available. The studies in Table 1 differed in their consideration of certain components in the life cycle of fertiliser manufacturing, particularly in relation to transport and GHGs other than CO_2.

Table 1: Summary of published studies into GHG emissions from Fertiliser Production.

Reference	**Country**	**Type**	**Results**						**Transparency**[b]
			Energy SwJensse	**CO_2** TDnen	**N_2O** and	**CH_4**	**Transport to manuf.**	**Transport to fields**	
Davis and Haglund (1999)	Sweden and Western Europe	Masters Thesis	Yes	Yes	Yes	Yes	Yes	No	Yes

3.1. Greenhouse Gas Emission Factors for Ammonia Production.

Ammonia (NH_3) is the primary input for the majority of worldwide nitrogen fertiliser production (DOE 2000; EFMA 2000a) and all nitrogen fertilisers considered in this review. Along with N_2O emissions from subsequent nitric acid production, CO_2 emissions from ammonia production dominate GHG emissions budgets for nitrogen fertiliser manufacture.

3.1.1. Overview of Ammonia Production.

Worldwide ammonia production is largely based on modifications of the Haber-Bosch process where NH_3 is synthesised from a 3:1 volume mixture of hydrogen and nitrogen at elevated temperature and pressure in the presence of an iron catalyst (Engelstad 1985). All the nitrogen used is obtained from the air and the hydrogen may be obtained by either of the following processes:

a) steam reforming of natural gas or other light hydrocarbons (Natural Gas Liquids, Liquefied Petroleum Gas or Naphtha); or
b) partial oxidation of heavy fuel oil or coal.

About 85% of world ammonia production is based on steam reforming concepts (EFMA 2000a). Natural gas is the preferred hydrocarbon feedstock (Engelstad 1985) with approximately 80% of world ammonia capacity being based on natural gas (EFMA 2000a and Patyk 1996).

The synthesis of ammonia is a very energy demanding process, with the current fertiliser manufacturers typically consuming around 25-35 GJ/tonne ammonia through the steam reforming process (see Davis and Haglund 1999, Kongshaug 1998, Patyk 1996, DOE 2000). The primary energy source for ammonia synthesis is natural gas. Thus, due to consumption of natural gas or other hydrocarbons both for the hydrocarbon feedstock and to meet energy requirements of the process, CO_2 emissions are the major component of GHG budgets for ammonia manufacture.

Importantly, many reactions along the production cycle of ammonia, nitric acid, sulphuric acid and several subsequent fertiliser products are exothermic and generate a net export of steam. In a LCA accounting framework, this steam export can be significant enough to warrant a net energy and emissions ‘credit’ (eg. Kongshaug

1998) or be considered to replace the combustion of fossil fuels elsewhere in the life cycle (eg. Davis and Haglund 1999). Table 2 provides a summary of how some studies interpreted this energy and emissions credit within the fertiliser life cycle.

Table 2: Interpretation of emissions credits from steam exports during fertiliser production.

Reference	Steam Credit	Notes from reference regarding emissions credit for steam production
Davis and Haglund (1999)	Yes	"In the case of generation of steam owing to fertiliser production, steam has been assumed to replace combustion of oil" (pp. 97). "The reactions involved in producing nitric acid reaction yield heat, which is partly transported to a district-heating network. The district heat energy is deducted from net energy consumption" (pp. 64).
Kongshaug (1998)	Yes	"Full credit has been given to steam export from production units. The most efficient ammonia, nitric acid and sulphuric acid plants have today very high surplus of energy, especially the sulphuric acid plants" (pp. 17).
West and Marland (2001)	No	"The energy balance credit comprised less than 2% of the total energy input into the production of N fertiliser and was not included in the estimate of CO_2 emissions" (pp. 6).
Mortimer (pers. comm.)	Yes	"There are many complications involved in the calculations, chiefly due to the need to assess ammonia and nitric acid production and the need to address a substantial steam export 'credit' (assumed to displace some natural gas use)".
Elsayed et al. (2003)	Yes	No details given.
Patyk (1996)	?	No discussion of steam credits was provided in the text. However, a negative emissions value for CO_2 was included in the emissions estimates for nitrogen fertilisers, which may infer a steam credit.
Patyk and Reinhardt (1996) Kuesters and Jenssesn (1998) Kramer (1999) Kaltschmitt and Reinhardt (1997)	Unknown	Insufficient information was provided to determine whether steam credits were included in analyses.

3.1.2. Emission Factors for Ammonia Production

Emission factors for ammonia production are presented in Table 3. CO_2 emissions arising from fossil fuels consumed as an energy source and feedstock dominated GHG emissions from ammonia synthesis, with emissions from other sources (eg. transport) making only minor contributions. Estimates were generally based on the quantity of energy consumed and the appropriate emission factors for the respective fossil fuel inputs. Natural gas was the primary fossil fuel for all estimates given in Table 3.

Given the lack of transparency of several reports, it is difficult to discuss the source of differences amongst emission factors. Variation can be attributed to the overall efficiency of each plant (related to plant age and design), the use of alternative fossil fuel inputs (i.e. coal and/or oil) and, to a lesser extent, the way steam exports were interpreted.

technologies (IPCC 2000). Non-Selective Catalytic Reduction (NSCR), a typical tail gas treatment in the USA and Canada, may reduce N_2O emissions by 80-90% (IPCC 2000) and a nitric acid manufacturer in Norway has developed a N_2O abatement process giving 70-85% N_2O reduction (Kongshaug 1998). Despite their advantages, an estimated 80% of the nitric acid plants worldwide do not employ NSCR technology (IPCC 2000).

3.2.2. Emission Factors for Nitric Acid Production

Emission factors for nitric acid production are given in Table 4. With the exception of Kramer (1999) and Mortimer (pers. comm.) the only GHG included is N_2O. Estimates are generally based on point source measurement of N_2O concentration in tail gases at nitric acid plants. In LCA studies where emissions credits from steam generated during nitric acid production were considered (see Table 2), the credit was generally applied elsewhere in the fertiliser production life cycle. Mortimer (pers. comm.) presented a small emission credit in this step of the fertiliser life cycle.

N_2O emissions from nitric acid production are highly variable with estimates ranging from 550-2945 g CO_{2-e}/kg Nitric Acid (Table 4). Variation among estimates can be attributed to the installation of emissions abatement technologies. It should be noted that emission factors as high as 5890 CO_{2-e} /kg Nitric Acid are given for plants not equipped with NSCR technology (IPCC 2000).

Table 4: Greenhouse gas emission factors for Nitric Acid Production

Product	Country	Composition[a]	g CO_{2-e}			Reference
		N:P:K	per kg N	per kg Product	CO_2:N_2O:CH_4	
Nitric Acid	USA	*22.2:0:0*	*2818.2-12681.8*	620-2790	0:100:0	IPCC (2000)
Nitric Acid	Norway – modern, integrated plant	*22.2:0:0*	*2818.2*	<620	0:100:0	IPCC (2000)
Nitric Acid	Norway – atmospheric pressure plant	*22.2:0:0*	*5636.4-7045.5*	1240-1550	0:100:0	IPCC (2000)
Nitric Acid	Norway – medium pressure plant	*22.2:0:0*	*8454.5-10568.2*	1860-2325	0:100:0	IPCC (2000)
Nitric Acid	Japan	*22.2:0:0*	*3100.0-8031.8*	682-1767	0:100:0	IPCC (2000)
Nitric Acid	Canada – without NSCR[c]	*22.2:0:0*	*11977.3*	2635.0	0:100:0	IPCC (2000)
Nitric Acid	Canada – with NSCR[c]	*22.2:0:0*	*2818.2*	<620	0:100:0	IPCC (2000)
Nitric Acid	USA – without NSCR[c]	*22.2:0:0*	*13386.4*	2945.0	0:100:0	IPCC (2000)
Nitric Acid	USA - with NSCR[c]	*22.2:0:0*	*2818.2*	620.0	0:100:0	IPCC (2000)
Nitric Acid	Sweden: Landskrona	*22.2:0:0*	*10244.1*	2253.7	0:100:0	Davis and Haglund (1999)
Nitric Acid	Sweden: Koping	*22.2:0:0*	*12710.0*	2796.2	0:100:0	Davis and Haglund

						(1999)
Nitric Acid	Europe Average	*22.2:0:0*	9000.0	*1980.0*	0:100:0	Kongshaug (1998)
Nitric Acid	Europe Modern Technology	*22.2:0:0*	2500.0	*550.0*	0:100:0	Kongshaug (1998)
Nitric Acid	Netherlands	*22.2:0:0*	*10851.9*	2387.4	22.5:77.1:0.3	Kramer (1999)
Nitric Acid	Europe	*22.2:0:0*	*9035.5*	1987.8	0:100:0[b]	Mortimer (pers. comm.)
(a) From Patyk (1996). This may vary for different nitric acid producers. (b) Mortimer gave a net credit for CO_2 and CH_4 of 85 and 4 g CO_{2-e}/kg Nitric Acid. (c) NSCR: Non-Selective Catalytic Reduction technology, see text. Note: Figures in *italics* are derived values, based on % N composition given in Patyk (1996).						

3.3. Greenhouse Gas Emission Factors for Ammonium Nitrate, Calcium Ammonium Nitrate and Other Nitrogen Fertilisers

3.3.1. Overview of AN, CAN and N Fertiliser Production

Emissions data were available for Ammonium Nitrate (AN), Calcium Ammonium Nitrate (CAN) and 'Mean Nitrogen Fertiliser'. AN is used extensively as a nitrogenous fertiliser across the world (EFMA 2000c, DOE 2000), and its derivative CAN is particularly important fertiliser in Europe (Davis and Haglund 1999; Patyk 1996). AN is produced by neutralising gaseous ammonia with aqueous nitric acid. The solution is evaporated and then formed into solid fertiliser by prilling or granulation (EFMA 2000c). Before solidification, the solution may be mixed with dolomite or limestone to make CAN (EFMA 2000c). 'Mean Nitrogen Fertiliser' refers to a range of different fertiliser types used in Europe (see Table 5 for details).

3.3.2. Emission Factors for AN, CAN and N Fertiliser Production

Table 5 presents the GHG emissions from AN, CAN and Mean N Fertiliser Production. With the exception of West and Marland (2001) from the US, estimates were based on plants in Western Europe. It should be noted here that the US estimate excluded N_2O emissions (West, pers. comm.), which are significant in total GHG emissions. Regardless of the omission of N_2O, the US estimate is still relatively low.

In all studies, the majority of these emissions are made up of CO_2 emissions from ammonia synthesis and N_2O emissions from nitric acid production. Based on available information from each report, N_2O emissions from nitric acid production accounted for an estimated 60-78% and 52-61% of total CO_{2-e} emissions from AN/CAN and Mean N Fertiliser production respectively (Table 5). Emissions arising from processing of intermediate products (i.e. ammonia and nitric acid) into final

products (i.e. CAN, AN etc.) were of relatively minor importance (Patyk and Reinhardt 1996; Davis and Haglund 1999).

Data for emissions from transport of raw materials and intermediate products were included in several studies. Patyk (1996), Patyk and Reinhardt (1996) and Davis and Haglund (1999) accounted for distances covered by truck, railway, inland navigation or boat, and calculated emissions based on published emissions factors. Neither included transport for distribution of the final fertiliser product. The contribution of transport to total emissions was minor (approximately 1% to 3%).

The effect of the steam credits generated at various stages of the AN/CAN life cycle is difficult to interpret in terms of overall emissions, given the lack of transparency of several reports. Data from Davis and Haglund (1999) suggest that the production of steam has only a minor impact on total GHG emissions (see 'Steam' in Table 5).

Table 5: Greenhouse gas emission factors for Ammonium Nitrate (AN), Calcium Ammonium Nitrate (CAN) and Mean N Fertilisers.

Product	Country	Composition	g CO_{2-e}					Reference
		N:P:K	per kg N	per kg Product			CO_2:N_2O:CH_4	
				Total[c]	Steam	Transport		
AN	European Average	35.0:0:0	*7030.8*	2460.8	-38.6	14.2	39.6:59.5:0.9	Davis and Haglund (1999)
AN	European Average	33.5:0:0	*6806.0*	2280.0	-	-	-	Kongshaug (1998)
AN	Europe Modern Tech.	33.5:0:0	*2985.1*	1000.0	-	-	-	Kongshaug (1998)
AN	Netherlands	*33.5:0:0*[a]	*7108.7*	2381.4	-	-	38.5:60.9:0.5	Kramer (1999)
AN	United Kingdom	*33.5:0:0*[a]	6536.6	*2189.8*	-	-	29.1:69.7:1.2	Elsayed (2003)
AN	Europe	*33.5:0:0*[a]	6726.0	*2253.2*	-	-	22.1:77.9;0.0	Kuesters and Jenssen (1998)
CAN	Sweden: Landskrona	27.6:0:0	*8467.1*	2336.9	-25.3	25.9	38.3:60.9:0.8	Davis and Haglund (1999)
CAN	Sweden: Koping 1	27.6:0:0	*9562.1*	2639.2	-50.1	25.2	33.4:65.9:0.7	Davis and Haglund (1999)
CAN	Sweden: Koping 2	27.2:0:0	*9562.9*	2601.1	-48.8	24.8	33.4:65.9:0.7	Davis and Haglund (1999)
CAN	Europe Average	*26.5:0:0*[a]	*7481.9*	1982.7	-24.4	20.1	39.8:60.6:0.9	Davis and Haglund (1999)
CAN	Europe Average	26.5:0:0	*6867.9*	1820.0	-	-	-	Kongshaug (1998)
CAN	Europe Modern Tech.	26.5:0:0	*3018.9*	800.0	-	-	-	Kongshaug (1998)
CAN	Netherlands	27.9:0:0	6810.0	*1900.0*	-	-	38.8:60.6:0.5	Kramer (1999)
Mean N Fert[d]	Germany	28.6	7615.9	*2178.1*	-	59.2	36.6:61.4:1.9	Patyk and Reinhardt (1996)
Mean N Fert[d]	Germany	27.7	5339.9	*1479.1*	-	18.0	45.0:54.8:0.1	Patyk (1996)
Mean N Fert[d]	Germany	*27.7*[b]	5644.6	*1563.6*	-	-	46.9:52.9:0.2	Kaltschmitt and

								Reinhardt, 1997)[f]
Nitrogen Fert.	US	-	857.5[e]	-	-	-	100:0:0	West and Marland (2001)

a) Composition of CAN and AN from Kongshaug (1998).
b) Composition of Nitrogen Fertiliser from Patyk (1996)
c) Transport *not* included in Total Emissions. Steam Credit *was* included in Total Emissions.
d) Mean emissions and composition from Ammonia, Nitric Acid, CAN, Urea AN, MAP, DAP, ANP.
e) This estimate is *exclusive* of N_2O emissions, see text.
f) Kaltschmitt and Reinhardt (1997) cited in Elsayed et al. (2003).
Note: Figures in *italics* are derived values, based on % N composition.

3.4. Greenhouse Gas Emissions Factors for Urea and Urea-Ammonium Nitrate Production.

3.4.1. Overview of Urea and Urea-Ammonium Nitrate Production

Urea accounts for almost 50% of world nitrogen fertiliser production (UNEP 1996). The synthesis of urea is based on the combination of ammonia and carbon dioxide at high pressure to form ammonium carbonate, which is subsequently dehydrated by the application of heat to form urea and water (EFMA 2000d). Liquid Urea-Ammonium Nitrate (UAN) is formed by mixing and cooling concentrated urea and ammonium nitrate solutions (EFMA 2000d).

3.4.2. Emission Factors for Urea and Urea-Ammonium Nitrate Production

Emissions factors for Urea and UAN are given in Table 6. Emissions from urea production are dominated by CO_2 emitted during ammonia synthesis. N_2O emissions account for a significant proportion of emissions from UAN production, because nitric acid is an intermediate product in ammonium nitrate synthesis.

Production of urea is usually linked to an ammonia plant, where by-product CO_2 from ammonia synthesis is used as a primary input in urea production. The discrepancy between emissions factors for urea in Table 6 may be attributed to how this utilisation of by-product CO_2 is interpreted within the fertiliser life cycle. Because Kongshaug (1998) and Kuesters and Jenssen (1998) were not conducting full LCA studies, they consider that this consumption of CO_2 constitutes a net reduction in by-product CO_2 emissions, hence the comparatively low emission factors. In contrast, Davis and Haglund (1999) did not include this net credit under the assumption that by-product CO_2 is only stored for a short time, and is eventually released upon application of urea fertilisers in the field. The IPCC (1996a, Section 2.13) recommends that "no account should be taken for intermediate binding of CO_2 in downstream manufacturing processes and products".

Table 6: Greenhouse Gas Emission Factors for Urea and Urea Ammonium Nitrate (UAN) Production.

Product	Country	Composition	g CO_{2-e}			Reference
		N:P:K	per kg N	per kg Product	CO_2:N_2O:CH_4	
Urea	Europe Average	46:0:0	*4018.9*	1848.7	97.5:0.1:2.3	Davis and Haglund (1999)
Urea	Europe Average	46:0:0	*1326.1*	610.0	-	Kongshaug (1998)
Urea	Europe: Modern Tech.	46:0:0	*913.0*	420.0	-	Kongshaug (1998)
Urea	Europe	*46:0:0*[a]	1707.3	*785.4*	-	Kuesters and Jenssen (1998)
UAN	Europe	*32:0:0*[a]	3668.0	*1173.8*	36.6:63.4:0.0	Kuesters and Jenssen (1998)
UAN	Europe Average	32:0:0	*5762.9*	1844.1	59.1:39.5:1.4	Davis and Haglund (1998)
UAN	Europe Average	32:0:0	*4093.8*	1310.0	-	Kongshaug (1998)
UAN	Europe Modern Tech.	32:0:0	*2000.0*	640.0	-	Kongshaug (1998)

(a) Composition from Kongshaug (1998).
Note: Figures in *italics* are derived values, based on % N composition.

4. Greenhouse Gas Emission Factors for Phosphate Fertilisers

In this section, published GHG emission factors for key phosphate fertilisers are presented and discussed. Emissions factors for Single Superphosphate (SSP), Triple Superphosphate (TSP), Diammonium Phosphate (DAP), Monoammonium Phosphate (MAP) and a 'Mean Phosphate Fertiliser' are provided. A discussion of the production process for phosphate fertilisers and the primary sources of emissions is included.

4.1. Overview of Phosphate Fertiliser Production

The phosphate fertilisers discussed here are produced from various combinations of phosphate rock, sulphuric acid, phosphoric acid and ammonia:

- Single Superphosphate (SSP): phosphate rock and sulphuric acid,
- Triple Superphosphate (TSP): phosphate rock and phosphoric acid,
- Mono- and Di- Ammonium Phosphate (MAP/DAP): phosphoric acid and ammonia.

The majority of the world's phosphate fertilisers are based on phosphoric acid (Kongshaug 1998). Fertiliser grade phosphoric acid is produced using the 'wet process', where sulphuric acid is reacted with naturally occurring phosphate rock

(EFMA 2000f; DOE 2000). Apatite minerals comprise the primary phosphate rock inputs. Phosphoric acid may be produced via the dihydrate process or more energy efficient hemihydrate process. The US and European phosphoric acid manufacturers typically use the dihydrate process (EFMA 2000f; DOE 2000).

Sulphuric acid is required for the production of phosphoric acid. More sulphuric acid is produced than any other chemical in the world and the largest single user is the fertiliser industry (EFMA 2000e). Sulphuric acid is usually made using the contact method, an oxidation process based on the burning of elemental sulfur (brimstone) (DOE 2000). Elemental sulphur is generally sourced from the oxidation of hydrogen sulphide from natural gas or crude oil, but can also come from sulphur mining (EFMA 2000e; DOE 2000). The sulphuric acid conversion process is highly exothermic, often resulting in a net export of energy from the more efficient sulphuric acid plants.

Ammonium phosphate fertilisers (MAP and DAP) are found in both solid and liquid forms and are produced by the reaction of phosphoric acid with anhydrous ammonia. Single superphosphate (SSP) is made by reacting ground phosphate rock with various concentrations of sulfuric acid and Triple superphosphate (TSP) is produced by combining ground phosphate rock or limestone with low concentration phosphoric acid (DOE 2000).

4.2. Greenhouse Gas Emission Factors for Phosphate Fertilisers

GHG emissions factors for phosphate fertilisers were available from six studies (Table 7). Most estimates were based on studies of European systems, with the sole exception being the study of West and Marland (2001) from the US. Emissions estimates are dominated by CO_2. Most of these emissions are related to the consumption of fossil fuels as an energy source for the various production processes involved in phosphate fertiliser production.

The net emission from phosphate fertiliser manufacture is largely determined by the method of sulphuric acid production. The estimates in Table 7 all assumed that the majority of sulphur used is recovered from natural gas and fuel oil. Consequently, no

emissions are linked to the sulphur raw material. The exothermic reactions involved in the production of sulphuric acid may generate a net energy export. This may be translated as an emissions credit (see Table 2) and has considerable bearing on emissions estimates. The effect of this emissions credit is well illustrated by the negative accumulated emissions estimate for Modern European DAP/MAP and SSP/TSP plants that are equipped with technology capable of capitalising on this energy surplus (Table 7; 'Europe Modern Tech', Kongshaug 1998).

Patyk (1996), Patyk and Reinhardt (1996) and Davis and Haglund (1999) each provided data on emissions from transport of raw materials and intermediate products during phosphate fertiliser manufacture. Transport comprised a considerable proportion of the emissions budget, making up about one-third of total emissions in Patyk (1996) and Patyk and Reinhardt (1996) and 20-25% of total emissions in Davis and Haglund (1999). Estimates took into account transport distances and appropriate emission factors for each mode of transport (i.e. sea, rail, road). The overseas transport of raw phosphate and P fertiliser was particularly important in the studies of Patyk (1996) and Patyk and Reinhardt (1996).

Insufficient information was provided to identify the source of the large discrepancy between 'European Average' emissions estimates from Davis and Haglund (1999) and Kongshaug (1998).

Table 7: Greenhouse Gas Emission Factors for Phosphate Fertilisers.

Product	**Country**	**Comp'n**	**g CO_{2-e}**					**Reference**
		N:P:K:S[d]	**Per kg N**	**per kg P_2O_5[d]**	**per kg product**		**CO_2:N_2O:CH_4**	
					Total[a]	**Transport**		
SSP	Europe Average	0:21:0:23	-	*1051.8*	220.9	70.4	93.3:1.1:5.7	Davis and Haglund (1999)
SSP	Europe Average	0:21:0:23	-	*95.2*	20.0	-	-	Kongshaug (1998)
SSP	Europe Modern Tech.	0:21:0:23	-	*-238.1*	-50.0	-	-	Kongshaug (1998)
TSP	Europe Average	0:48:0:0	-	*1083.5*	520.1	170.5	96.7:0.5:2.8	Davis and Haglund (1999)
TSP	Europe Average	0:48:0:0	-	*354.2*	170.0	-	-	Kongshaug (1998)
TSP	Europe Modern Tech.	0:48:0:0	-	*-416.7*	-200.0	-	-	Kongshaug (1998)
	N and P Compound Fertiliser							
MAP	Europe Average	11:52:0:0	6392.9	*1352.4*	703.2	238.1	97.9:0.3:1.9	Davis and Haglund (1999)
MAP	Europe Average	11:52:0:0	2818.2	*596.2*	310.0	-	-	Kongshaug (1998)
MAP	Europe Modern Tech.	11:52:0:0	-2454.5	*-519.2*	-270.0	-	-	Kongshaug (1998)

DAP	Europe Average	18:46:0:0	4812.0	*1883.0*	866.2	211.3	97.8:0.2:1.9	Davis and Haglund (1999)
DAP	Europe Average	18:46:0:0	2555.6	*1000.0*	460.0	-	-	Kongshaug (1998)
DAP	Europe Modern Tech.	18:46:0:0	-388.9	*-152.2*	-70.0	-	-	Kongshaug (1998)
Mean P Fert[c]	Germany	0:32.2:0:0	-	817.3	*263.2*	116.1	93.8:1.0:5.2	Patyk and Reinhardt (1996)
Mean P Fert[c]	Germany	0:38.8:0:0	-	458.0	*177.7*	103.0	97.8:2.1:0.1	Patyk (1996)
Mean P Fert[c]	Germany	0:35.5:0:0[b]	-	700.0	*248.5*		100:0.0:0.0	Kaltschmitt and Reinhardt (1996) [e]
P Fertiliser	US	-	-	165.1	-		100:0.0:0.0	West and Marland (2001)

a) Total emissions *do not* include Transport.
b) Assumed as average of Patyk (1996) and Patyk and Reinhardt (1996)
c) Mean P Fertiliser includes Phosphoric acid, SSP, TSP, MAP, DAP and ANP.
d) For West European products the grades are given in weight fraction of Nitrogen (N), phosphorus oxide (P_2O_5) and potassium oxide (K_2O)
e) Kaltschmitt and Reinhardt (1997) cited in Elsayed et al. (2003).
Note: Figures in *italics* are derived values, based on % N or P_2O_5 composition.

5. Greenhouse Gas Emission Factors for NPK Fertilisers

5.1. Overview of NPK Fertiliser Production

There are several ways to produce multi-nutrient NPK fertilisers. In Europe, the two common routes are the nitrophosphate route and the mixed acid route (EFMA 2000g). An alternative method involves simply mixing dry fertilisers. The mixed acid route requires phosphoric, sulphuric and nitric acids as raw materials. These acids are mixed and then neutralised with gaseous ammonia. Other compounds containing potassium and magnesium are subsequently added. In the nitrophosphoric acid route, the first step involves reacting phosphate rock with an excess of nitric acid to produce a mixture of nitric and phosphoric acid and calcium nitrate. The calcium nitrate is extracted, and the remaining solution is then neutralised with ammonia. Potassium (K) is added as potassium chloride (KCl) or Potassium sulphate (K_2SO_4) salts.

5.2. Greenhouse Gas Emission Factors for NPK Fertilisers

GHG emission factors were available from only two studies (Table 8). Estimates were based on emissions data for Swedish NPK producers, average European manufacturers and European modern technology. The composition of these fertilisers and the processes used to produce them varied markedly. Most of the CO_2 emissions originated from ammonia production because of the large consumption of fossil fuels

(see Section 3). Almost 100% of total N_2O emissions were released during the production of nitric acid; other processes such as the extraction of rock phosphate and production of sulphuric acid and phosphoric acid were not important (Kongshaug, 1999).

Table 8: Greenhouse Gas Emissions from NPK Fertilisers.

Product	**Country**	**Comp'n**	**g CO_{2-e}**						**Reference**
		N:P:K[b]	**per kg N**	**per kg P**	**per kg K**	**per kg product**		**CO_2:N_2O:CH_4**	
						Total[a]	**T'sport**		
NPK	Sweden:Koping	17:04:13	*9416.0*	*40018.2*	*12313.3*	1600.7	29.9	40.2:59.0:0.8	Davis and Haglund (1999)
NPK	Sweden:Koping	20:05:04	*9545.8*	*38183.2*	*47729.0*	1909.2	29.9	37.9:61.4:0.8	Davis and Haglund (1999)
NPK	Sweden:Koping	21:03:10	*7973.6*	*55815.0*	*16744.5*	1674.5	30.2	38.3:60.9:0.8	Davis and Haglund (1999)
NPK	Sweden:Koping	21:04:07	*8660.1*	*45465.3*	*25980.2*	1818.6	31.3	39.6:59.7:0.8	Davis and Haglund (1999)
NPK	Sweden:Koping	24:04:05	*8602.4*	*51614.2*	*41291.3*	2064.6	32.1	38.3:61.0:0.8	Davis and Haglund (1999)
		N:P:K[b]	**per kg N**	**per kg P_2O_5**	**per kg K_2O**	**per kg Product**		**CO_2:N_2O:CH_4**	
						Total[a]	**T'sport**		
NPK (Acid)	Europe Average	15:15:15	*7495.6*	*7495.6*	*7495.6*	1124.3	86.4	52.1:46.9:1.0	Davis and Haglund (1999)
NPK (Nitro)	Europe Average	15:15:15	*7895.7*	*7895.7*	*7895.7*	1184.4	39.5	50.8:48.2:1.1	Davis and Haglund (1999)
NPK (Acid)	Europe: Average	15:15:15	*6466.7*	*6466.7*	*6466.7*	970.0			Konshaug (1998)
NPK (Nitro)	Europe: Average	15:15:15	*5533.3*	*5533.3*	*5533.3*	830.0			Konshaug (1998)
NPK (Mix)	Europe: Average	15:15:15	*2600.0*	*2600.0*	*2600.0*	390.0			Konshaug (1998)
NPK (Mix)	Europe: Average	15:15:15	*2266.7*	*2266.7*	*2266.7*	340.0			Konshaug (1998)
NPK (Acid)	Europe: Mod Tech.	15:15:15	*2133.3*	*2133.3*	*2133.3*	320.0			Konshaug (1998)
NPK (Nitro)	Europe: Mod Tech.	15:15:15	*2733.3*	*2733.3*	*2733.3*	410.0			Konshaug (1998)
NPK (Mix)	Europe: Mod Tech.	15:15:15	*400.0*	*400.0*	*400.0*	60.0			Konshaug (1998)
NPK (Mix)	Europe: Mod Tech.	15:15:15	*800.0*	*800.0*	*800.0*	120.0			Konshaug (1998)

a) Total emissions *do not* include transport.
b) According to Swedish standard, the grades are given in weight fraction (%) of nitrate (N), phosphorus (P) and Potassium (K). In the case of West European products the grades are given in weight fraction of Nitrogen (N), phosphorus oxide (P_2O_5) and potassium oxide (K_2O)
Note: Figures in *italics* are derived values, based on % N or P_2O_5 composition.

6. Summary

This report collates published greenhouse gas (GHG) emission factors associated with the production of a range of nitrogen, phosphate and multi-nutrient fertilisers, for use in agricultural and forestry Life Cycle Assessments. Overall, there were few published studies that present GHG emission factors for fertiliser production and, with the exception of one study from the US, all were based on fertiliser manufacture in Western Europe. Emission factors for the intermediate products Ammonia and Nitric Acid were more widely available, but these are less useful in an agricultural LCA context.

The major GHG emissions associated with nitrogen-containing fertiliser production are carbon dioxide (CO_2) emitted when natural gas is combusted as part of ammonia synthesis, and nitrous oxide (N_2O) emitted during nitric acid production. For Phosphate Fertilisers, GHG emissions were primarily CO_2 emitted during the consumption of fossil fuels used in the various production processes. Transport of raw materials was an important contributor to phosphate fertiliser GHG emissions.

For each fertiliser product, emissions factors varied markedly between studies. This variation is due to differences in plant design and efficiency, emissions control mechanisms and raw material inputs. Differences may also be attributed to assumptions made by the analysts during the calculation of the emission factors, particularly in relation to the interpretation of energy and emissions credits and transport considerations. An understanding of these factors is required to make an informed decision as to which emissions factor is most applicable for the particular fertiliser product being considered for a specific study.

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